Purchase price optimization by demand allocation to suppliers based on the performance attributes

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ABSTRACT

Selection of the right supplier is always a challenge for the firm. Identifying the right supplier and allocating the optimum demand is always the critical part of supplier management in procurement industry. Cost and high-quality raw material are the two factors critical for reducing the manufacturing cost. This paper discusses about the two different approaches for optimization of the cost to realize the potential savings opportunities. It also proposes to two models to optimize the cost of purchasing by allocating the demand to the suppliers based on their performance attributes. The objective is to minimize the overall purchasing cost by considering the monetary effect associated with the supplier's performance. Comparative analysis of Linear optimization model and lexicographic for optimum demand allocation to the supplier's selected based on the performance of the suppliers is done to understand the better model based on the business requirement of the firm and thus reducing the overall purchasing cost.The outcome of the model will guide the managers to make better decisions while allocating the demands based on the priority of the business and save the purchasing cost by optimization of the demand allocation.

Keywords

Purchasing, Linear optimization, Lexicographic method, supplier selection, demand allocation, Procurement, PILP

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Introduction

Procurement has become one of the most crucial function for the organizations in the times of diminished world boundaries for trade. Procurement process involves identification of the supplier for the delivery of the right product at right time with right quality and quantity.Procurement between a manufacturer and suppliers is considered in two aspects i.e., supplier selection and order allocation.Cost has always been the most important factor for the organization to gain the competitive advantage over the rivals. A typical supplier has the spends around 60% of total sales income for raw material and consumables procurement (Krajewski, 2007). Around 70% of the product cost is taken up by the procurement of goods and services, according to a report((Ghodsypour, 1998). Thus, reasonable purchasing cost and high-quality raw material becomes crucial for reducing the overall manufacturing cost and right supplier selection will result in reducing the overall cost, increasing profitability, product qualityleading to overall competitiveness boost by rapid response to the customer's demand(Singh, 2014).

In supplier selection and demand allocation various metrics are specified and evaluated against different supplier's attributes. The criteria considered for supplier evaluation are qualitative as well as quantitative. While for qualitative data various techniques have already been discussed in multiple research paper, a lot of good work is also done on solving the supplier selection issue by evaluating both quantitative as well as qualitative metrics.(Dickson, 1966) in his study, identified 23 criteria of problems related to supplier selection. He suggested in his report that the quality, performance history and delivery are the three most important criteria.Although, many papers have revealed significant number of criteria affecting the supplier selection, according to (Charles A.Weber, 1991),the net cost, delivery and quality are considered to be the most important criteria for evaluating supplier performance..

After selecting the performance metric for selecting the supplier and allocating the demand, the scoring is assigned by the stakeholders in case of qualitative metrics to make it quantifiable and various approaches are used to solve the problem. (Charles A.Weber, 1991)in his literature review of almost 74 research papers concluded that there are there approaches to solve the problem of supplier selection linear weighting, mathematical programming and probabilistic approaches. Over a period of time, many approaches have been used for the problem including Analytic Hierarchy Process (AHP), Data Envelopment Analysis (DEA) and some hybrid methods (Singh, 2014). These methods although make an effort to convert the qualitative data into quantitative metric and use it effectively for supplier selection, but there is a high chance of biasness and the weightage of the actual performance metric may get underestimated.

Thus, to find the best suppliers and order allocation to the selected suppliers based on the quantitative data, linear optimization and Pure Integer Linear Programming using lexicographic method is proposed in this paper. The paper compares the output of linear optimization model and PILP model. The linear optimization model realizes the monetary impact of the delivery and quality metric and identifies the supplier with the lowest cost. The PILP lexicographic model ranks the criteria based on the business decisions and solves the objective in the same order to give the best suppliers with demand allocation. The paper is structured as followed. The next section talks about the literature review with a focus on how previous work done in demand allocation field. Section 3 discusses about the formulation of the models used to solve the optimization problem. Section 4 presents the methodology to allocate the demand and select the supplier using linear optimization and lexicographic method. Section 5 describes the numerical example and the performance analysis of both the models. Section 6 reports the results and the discussion over the application of the models on randomly generated data. Section 7 discusses the final conclusion which includes the limitation of the paper and managerial implication of the results along with the future research directions.

Literature Review

Various research papers have highlighted the importance of the supplier selection being important to reduce the overall operational cost. Selection of supplier and allocation of the demand happens simultaneously. While we consider the performance attributes of the suppliers like delay in the delivery, the cost of the item and the rate of defective, it is desirable to make the compromise among the conflicting criteria. Although most buyers consider cost as the primary metric, various metrics are also explored in the past as the supplier selection criteria. While most of the techniques involve the fuzzy method, AHP and DEA, the paper discusses how the quantitative performance metrics of the suppliers can be leveraged to make the informed decision of the demand allocation to save some cost. The decisions pertaining to purchasing has gained more weightage with the increasing significance of the purchasing activities. As organizations reliance on suppliers increase significantly, the decision-making gets severely affected and has severe direct and indirect consequences (Luitzen de Boer, 2001).
The literature review discusses two different techniques and approaches used for purchase price optimization by optimum demand allocation to the suppliers based on their performance attributes. A brief description of two methodologies, criteria is discussed in the following section.

Table 1 List of Criteria

Sr. No	Criteria
1.	**Purchasing cost**
2.	**Delay in Delivery rate**
3.	**Defective rate (Quality)**

Our first model considers the linear optimization technique using the solver in MS-Excel. The concern in the solver is it cannot solve the multi objective techniques. The cost is the most important factor while selecting the supplier. Hence, this model converts the delivery delay and defect rate of the supplier into cost parameter. The logic of converting rate of defective into cost was that every defective item will lead to loss of the potential sales and thus the conversion formula was directly related to the cost per unit, total quantity ordered and defect rate of the supplier(Charles A.Weber, 1991). The objective is to identify the supplier with optimum defect rate in delivery by considering the cost associated with the defective quantity.
The second attribute is rate of delay in the delivery(Charles A.Weber, 1991). The delay in the delivery of orders leads to loss of business for that cycle or can lead to high inventory for the next cycle.Thus, here we considered that 1% of delay in the delivery rate will eventually increase the cost of holding the inventory. The final model will be the linear optimization solved using the solver.
The second model prioritizes the performance attribute of the supplier and then allocates the demand based on the business priority. This is also considered as the lexicographic method.(Cococcioni, 2017)

1.1 Linear optimization

Linear optimization is the technical approach to achieve the best results in a mathematical model where the relationships are linear in nature.In this technique, the objective functions and the constraints are linear functions of the decision variables. (Taha, 2008)has suggested that linear programming is used to solve problems with identified variables, constraints and objective function. Besides problems that are production mix, LP can also be used for problems pertaining to the resources allocation(Taha, 2008). Optimization is the mathematical technique to identify the most optimal solution with the limited resources available with the organization. The resources can be Man, Machine, Material of any typical organization. In practical life problems the optimization in the organization is mostly cost minimization and profit maximization by utilizing the available resources. One of the most common method used is Simplex method. However, the linear optimization problems are solved using the tools like Solver, Lindo etc.

1.2 Lexicographic method

Lexicographic method is the technique of solving the optimization problem where multiple objectives are to be achieved. In this technique multiple objectives are not required to be converted in to one unit or common variable like we did in Linear optimization using solver. This method involves a process of prioritizing the objectives and ranking them based on their importance as a criterion. Thus, the need to assign weight to the objectives is eliminated.The objective function becomes the prioritized deviational variables and solves sequentially beginning with the from the highest priority level to the lowest(U.C.Orumie, 2013). The objective with the most noteworthy need is solved as single objective-problem.Further, with an added constraint next objective is solved as single- objective function.So, the constrained will be defined as $f1(x) <= f1(x1^*)$, where $x1^*$ is the global optimum solution of the primary objective function. The series of single optimization problems are solved by repeating the process of solving the objective functions.(Kuang-Hua-Chang, 2015). The algorithm gets terminated after achieving the optimum value. Introducing the new constraints lead to change in the optimal solution of first objective function.

Model Formulation

Certain assumptions were required to be made owing to the limitations of the data availability and the scope of the research.

Assumptions

The Pure Integer Linear Programming (PILP) model has the following assumptions:

- Supplier capacity, Demand, cost is taken as constant and known.
- Raw material shortage is not allowed from suppliers and inventory calculations is not considered.
- One raw material is considered.
- Each supplier has limited capacity.

1.3 Using solver- excel

The model was built for solving it in the excel, due to the time constraints in the project. In order to explain the business logic of the model, the optimization was done in the excel and later Lingo was used for the comparison as Excel has its own limitations. The solver function was used in the excel.

Excel solver is used to solve this linear optimization problem. The single objective is to minimize overall cost of and optimum demand allocation to the selected suppliers. The objective function for this model is minimizing overall purchasing cost.

Table 2

Data variables

Supplier Name	50 suppliers were selected number serially
Per unit Cost	This the cost of the product reaching at the gate.
Capacity	Capacity of the supplier
Minimum Business to be done with supplier	Minimum criteria to do business with the supplier
Maximum Business to be done with the supplier	Maximum criteria to do business with the supplier
Minimum Quantity supplier expects to supply	Quantity supplier is willing to do business with the customer, lower than that order cannot be taken by the supplier
Percent defect rate	Defect rate of the supplier
Delivery late	Rate of late delivery of the supplier
Cost_of_defective	Calculated cost realized of defective
Late_delivery_cost	Calculated cost realized of the late delivery

Decision variable

x_i : Order allocation to the supplier i

Parameters

D- aggregate demand of the item for the planned period
n- number of suppliers competing for selection
Ri - price of a unit item of the ordered quantity xi from the supplier i
Pi - percentage of the rejected units delivered by the supplieri
Ti- percentage of the late delivered units by the supplieri
Ui- upper bound of the quantity available with supplieri
L_i: lower bound of the quantity available with supplieri
q_i: Minimum order below which supplier won't take the order
c_i = Capacity of the supplier i
s_i= Selected Supplier
Objective:To identify the supplier and allocate the demand with the lowest purchasing cost

Mathematical Formulation

Minimize $Z = \Sigma x_i * R_j + \Sigma x_i * P_j + \Sigma x_i * T_j$ (1)

Subject to $\Sigma x_i = D$ (2)
$x_i >= 0$
$x_i >= c_i$ (4)

1.4 Using Lexicographic method

In this method the most significant criterion is given the first priority. The suppliers are compared and selected based on this criterion. Thus, the supplier selection criteria are ranked in the order of their importance. We choose the suppliers that are better than the other suppliers and satisfy the criteria, if not we compare the suppliers for the second important criterion. Thus, this method gives us the optimum solution by minimizing the objective functions starting with the most important and then the subsequent order of the important objectives. The important thing to note here is that the business decides the order of the objectives based on their requirements.

As the objective is to minimize the purchasing cost, number of late deliveries and number of defectives, this method will set the ranking of the objectives and select the supplier with minimum parameters in the same order.

Table 3

Data Variables:

Supplier Name	50 suppliers were selected number serially
Per unit Cost (R_i)	This the cost of the product reaching at the gate.
Capacity (c_i)	Capacity of the supplier
Minimum Business to be done with supplier (L_i)	Minimum criteria to do business with the supplier
Maximum Business to be done with the supplier (Ui)	Maximum criteria to do business with the supplier
Minimum Quantity supplier expects to supply (q_i)	Quantity supplier is willing to do business with the customer, lower than that order cannot be taken by the supplier
Percent defect rate (P_i)	Defect rate of the supplier
Late Delivery (T_i)	Rate of late delivery of the supplier
Supplier Select (i)	Determines the selection of the supplier from the list
Supplier Order allocation (x_i)	Denotes the demand(order) allocated to the specific supplier

The assumptions remain the same as considered for Excel solver method.

Objective: To minimize the cost, Late Delivery and Percent defect rate

Mathematical formulation:

Minimize $Z_1 = \Sigma x_i * R_i$ (Cost) (5)
Minimize $Z_2 = \Sigma x_i * P_i$ (Defective rate/Rejected units) (6)
Minimize $Z_3 = \Sigma x_i * T_i$ (Delay in Delivery)

Variables: In this method for the problem discussed, the variable Supplier Select (s), determines whether the supplier should be selected or not. The Supplier Order allocation (x_i) determines the order allocated to the supplier i.

Subject to $\Sigma x_i * (1 - P_i) = D$ (8)
$\Sigma x_i <= c_i * i$
(order allocation to supplier to supplier <= capacity of the selected supplier)
$\Sigma x_i <= U_i * i$
$\Sigma x_i >= L_i * i$
$\Sigma x_i >= q_i * i$

Methodology

In linear optimization problem, since the three metrics have different unit of measurement, it is essential to consider the cost impact of the delay in the delivery rate for the supplier and the defective rate of the supplier. This will create a single major objective function which is optimization of the overall purchasing cost. The objective function of multi-objective problem is transformed into the optimization problem with single objective and solved subjected to the constraints.

In PILP lexicographic method, we rank the quality as the first and the most important criteria. The suppliers are evaluated based on the quality metric. We check the global optimal value of the quality metric and observe the demand allocation to the supplier selected by the model. Further, using the sensitivity analysis, we identify the global optimal value of the delay delivery metric against the quality metric. The third ranked priority is the cost of the item proposed by the supplier. Thus, after optimizing for first two objectives, the model optimized for the third objective of cost. The experimental results on the randomly generated data of both the models is discussed in the following section.

Illustrative example and performance

The demonstration of the efficacy of the two models is done by using the sample data of 7 suppliers. The manufacturer wants to buy an item from the list of 7 suppliers and the corresponding supplier's data is shown in the table below.

Demand = 2200

1.5 Using excel solver

The defective percent and late delivery rate were converted into cost parameter for linear optimization as shown in the figure 1 below.

Fig.1: Cost conversion of late delivery rate and Defect rate

Suppliers	Cost per Unit(Ql)	Capacity	Min_Business	Max_Business	Min_Qty	Percent_defect rate	Delivery_late	Cost_of_defective	Late_delivery_cost
1	10.00	1250	100	1200	100	0.025	0.03	0.25	0.01
2	11.50	1500	100	1200	200	0.045	0.05	0.52	0.02
3	12.00	1200	100	1200	250	0.05	0.06	0.60	0.03
4	9.50	1100	100	1200	350	0.035	0.15	0.33	0.05
5	10.50	700	100	1200	100	0.015	0.00	0.16	0.00
6	12.15	950	100	1200	300	0.06	0.03	0.73	0.01
7	15.00	1000	100	1200	250	0.02	0.02	0.35	0.01

Late delivery of the item leads to either the stock out and lead to loss of sales in the same cycle or increase in the inventory of the next cycle. Thus, in the calculation of the late delivery cost, we considered the cycle of 30 days and divided the overall late delivery cost by 30 which gave us the cost per day.

This implies that if the delivery is delayed by n days the potential loss of sale or increase in the inventory will be late delivery cost per day into number of days(n).

As we run the model, the output of the model gives us the demand allocation to the supplier. We can see that our model has identified the supplier 1 and supplier 4 to meet the demand of 2200 units with optimum cost. Overall optimized cost of the purchasing was **22155.**The excel solver output image is given in appendix 1.

1.6 Lingo- Lexicographic method

When we solve the problem using the lingo software, based on the types of the variables and the constraints of our model. While solving for this example, the model class was PILP i.e. Pure Integer Linear Program. In PILP, all the expressions are linearand all variables are restricted to integer values.

For this problem, we first consider defective rate as the first priority. Using Lingo, we get the global optimal solution and order allocation to the suppliers based on the lowest rate of defectives. The second criterion chosen is the delay in the delivery. We identify the optimal value of delivery rate against the optimal value of the defective rate as shown in the table. For this we reduce the defective rate by 5 units and identify the corresponding optimum value of late delivery.

1.7 Sensitivity analysis

Sensitivity analysis reflects the optimum value of the later delivery rate against the varying defective rate as shown in the table 4. As observed, the variance in the optimal value of late delivery is insignificant after the rate of 55. Thus, business may decide to set the objective of defective rate at 55 acceptable for supplier selection.

Table 4 Sensitivity analysis of defective rate and late deliveries

Defective rate	Late deliveries (global optimum)
48	99
50	63.62
55	55.5
60	54.46
65	52.92
70	51.89

After freezing the value of defective rate, we reduced the late deliveries rate by 5 units and calculated the cost per unit as shown in the table 5. The decrease in the cost of insignificant after the rate of late delivery of <=65 units, which is Rs. 21167.

Table 5 Sensitivity analysis of cost and late delivery

Defective rate	Late deliveries	Cost(Rs.)
<=55	<=55.55	22336
<=55	<=60	22142
<=55	<=65	21167
<=55	<=70	21167

Results and discussion

The table 6 compares the output of the two models. The demand allocation using the lexicographic method in the Lingo software prioritized the objectives and allocated the demand after selecting the supplier. The overall cost incurred in the purchasing is lesser than the linear optimization technique.

Table 6 Result

	Linear Optimization solver	Excel	Lexicographic in Lingo		
Supplier Selected	Supplier 1	Supplier 4	Supplier 1	Supplier 5	Supplier 7
Demand allocation	1100	1100	1063	677	315
Overall cost (Rs.)	22155		21167.5		

The supplier selection and demand allocation using the lexicographic method is shown in the Appendix 2. The output important output of the model is the global optimal solution of the cost. The most optimum cost to fulfil the demand of 2200 units, considering all the objectives in their order of importance turns out to be **Rs. 21167.50**

Thus, with the help of randomly generated data, the supplier selection problem was solved using the two different methodologies.

Conclusion

The research work discusses the comparison of two models to optimize the purchase price by allocating the demand with the minimum purchasing cost. The lexicographic method discusses about setting the priority and that can be dynamic based on the business decision. The lingo software used during this work was a trial version and hence we had to limit the data to 7 suppliers. The premium tools can be used to solve the practical problem where more than 10 supplier's data can be analysed. Due to software limitation, the Lingo could sometime give the local optimal solution which may mislead the outcome as there could be multiple local optimal solutions. Hence, high performing solver can be used to overcome this problem.

Further, the research can be extended by using the goal programming in order to solve the linear problems with more than objective. Lexicographic method in Lingo software can be leveraged to consider the other parameters like the distance of the supplier, inventory level and optimize the cost while satisfying the multiple objectives. The optimization can also be studied by changing the order of the rank of the objectives to be achieved in the future research.

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